DEVELOPMENT OF THE CAPTURED FUELS TEST KIT

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This report details development of a portable test kit to allow an unskilled operator to quickly judge the usability of an undocumented fuel source in a compression ignition engine and in turbine-powered ground equipment. The test kit provides a means to measure a fuel's visual appearance, density, and viscosity. Cutoff limits were chosen for each of these parameters based on justifiable criteria. Novel approaches for falling ball viscometer reference tubes, a density indicator, and temperature compensation for the density test were developed.

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FOREWORD

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I. INTRODUCTION AND BACKGROUND

A simple fuel tester is required to enable isolated combat units to identify field expedient fuels for use in ground combat vehicles. The current systems of petroleum testing kits, sets, and laboratories are either too complex or too large to be deployed and used by combat vehicle crewmen. As a result, there exists a need to provide a highly portable, simplistic device which the combat crewman can quickly use to determine fuel type and relative quality. Since the Army's turbine-powered ground equipment are highly fuel tolerant, it was concluded that any emergency or field-expedient fuel determined by the Captured Fuels Test Kit (CFTK) to be suitable for use in Army diesel engines would also be suitable for use in the turbine-powered ground equipment.

This CFTK will provide measurable increases in reliability when evaluating field expedient petroleum fuels.

II. DESIGN GOALS FOR THE CFTK TESTER

In view of the stringent requirements for battlefield conditions, the following design concepts were incorporated:

- One person operation
- Compact, portable
- No electronic components
- No external power source required
- Minimum training time, easy to use
- Generally free from potential operating problems
- Maintenance free
- Require no calibration
- Rugged, droppable
- Must not leak fuel
- Does not allow dirt inside density/viscosity tester since debris can interfere with close tolerances in sample viscosity tube
- Operational in temperature range of $0^{o}C$ to $40^{o}C$
- Able to use while wearing MOPP gear

- Requires fuel sample size of 500 mL or less
- Total test duration time not to exceed 5 minutes
- Uses only fuel-resistant materials for tester components
- Compatible with all hydrocarbon fuels
- No logistical support
- Minimum time to fill and drain
- Minimum shelf life of 10 years

III. CHOICE OF FUEL PARAMETERS TO BE MEASURED BY THE CFTK

Ideally, the CFTK would be designed to provide a measure of the performance of a given fuel, in a compression-ignition engine, such as cetane number. However, tests for cetane number, or even calculated cetane index, do not meet the requirements placed on this test kit (i.e., field portable, quick, easy, no logistical support required, etc.) using current technology. Density, viscosity, and visual appearance were selected as the parameters to be measured since they do meet simple operational requirements. These parameters are not necessarily good predictors of overall fuel performance, but were judged to be acceptable screening tools since there are some density and viscosity differences between the various types of fuels (i.e., diesel, gasoline, JP-4, etc.). Additionally, within limits, the more dense and more viscous a petroleum fuel is, the better it tends to be as a compression-ignition engine fuel. In general, cetane number increases with density.

The pass/fail limits for the CFTK were selected based on the use of fuel specification tables for specific properties (when available) for a fuel. Other fuel data incorporated in the determination came from an earlier technical report*: "Emergency Fuels Technology." These data were averaged and utilized as an estimate of a fuel's maximum and minimum limits.

As can be seen in Table 1, the lower density cutoff (0.78 kg/L) represents a compromise of the minimum and maximum values for the various fuels shown in

* Bowden, J.N. and Stavinoha, L., "Emergency Fuels Technology," Interim Report AFLRL No. 155, AD A125275, prepared under Contract No. DAAK70-80-C-0001, June 1982.

TABLE 1. SPECIFICATION DETERMINATION OF MINIMUM AND MAXIMUM TEST LIMITS FOR CAPTURED FUELS TEST KIT

	Density, D 1298, kg/L at 15°C (estimated value)		Kinematic Viscosity, D 445 at 40°C, cSt (estimated value)	
	Min	Max	Min	Max
DF-1	(0.786)	(0.829)	1.3	2.9
DF-2	(0.809)	(0.878)	1.9	4.1
OCONUS DF-2	0.815	0.860	1.3*	5.3*
JP-8	0.775	0.840	1.08	-
JP-4	0.751	0.802	(0.75)	(0.82)
Gasoline	(0.720)	(0.750)	0.5**	-
Jet A	0.775	0.840	(1.1)	(1.7)
Burner Oil	-	0.875	2.0	3.6
DF-A	-	-	1.1	2.4

* Calculated from limits of 1.8 to 9.5 cSt at 20°C.
** Determined at BFLRF as average viscosity.

Table 1. The initial lower viscosity range was set at 1.1 cSt at 40°C in an attempt to include all DF-A, JP-8, and Jet A procurable fuels as suitable fuels. However, a 50/50 blend of gasoline and a high viscosity diesel fuel can also produce a viscosity of 1.1 cSt or greater at 40°C, and this fuel is not acceptable for compression-ignition engines.

Figure 1 is a plot of gasoline composition in a gasoline/diesel fuel blend versus calculated viscosity. The curve shown could be considered a worst-case example since the viscosity of the diesel fuel is assumed to be 5.3 cSt at 40°C (F-54, DF-2 upper viscosity limit). Even at 50-percent gasoline, the viscosity of the blend is within the lower limits for JP-8, Jet A, and DF-A. The lower viscosity reference liquid is currently set at 1.3 cSt at 40°C. This limit has the potential to eliminate several acceptable fuels, but is necessary to eliminate a blend/mixture that would not be usable within the context of a field expedient or emergency fuel.

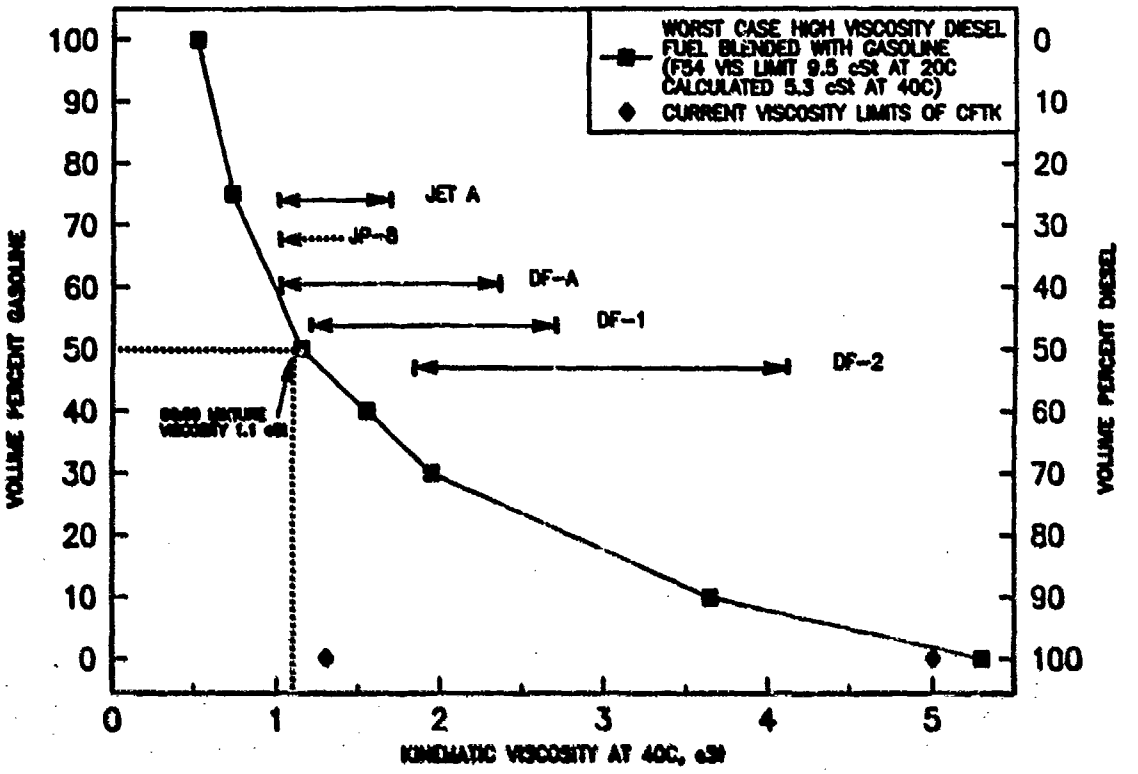

FIGURE 1. VISCOSITY OF GASOLINE AND DIESEL FUEL BLENDS

IV. PRELIMINARY DESIGN CONCEPTS

A. Density

Several methods to determine density were considered and evaluated. The most promising methods appeared to be calibrated spheres of varying density which would sink or float in the test fluid (a configuration for this approach is depicted in Figure 2), conventional hydrometer-type evaluation of density, or a buoyant pointer that would rotate in the test fluid as fluid densities varied.

1. Calibrated Spheres

Calibrated spheres were determined to be unsuitable due to the difficulty of procuring spheres made from fuel resistant materials in the proper density ranges and desired physical size. It was also judged that temperature compensation would possibly be more of a problem with this approach.

2. Hydrometer

Testing with a hydrometer indicated that it is a suitable approach. The hydrometer proved to be accurate and relatively easy to compensate for temperature. The only major problems identified with the hydrometer approach is that the hydrometer is sensitive to breakage if dropped and would have to be secured within its sample tube when not in use.

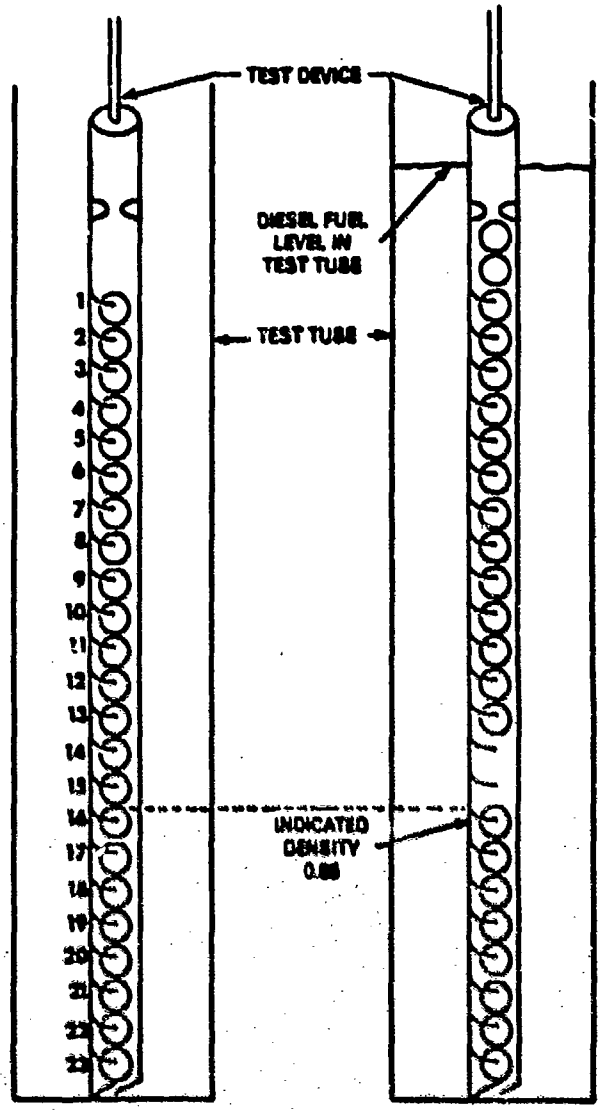

FIGURE 2. APPROACH FOR USING CALIBRATED SPHERES TO MEASURE DENSITY

3. Buoyant Pointer

The buoyant pointer approach (based on Patent Nos. 4,136,551 and 4,236,405) was selected as the most promising approach since it allowed a compact final design, and would possibly be relatively simple to compensate for temperature variations.

B. Viscosity

Two approaches were considered and tested for obtaining viscosity measurements.

1. Calibrated Orifice

A calibrated orifice was used to determine viscosity by measuring the time period required for a fixed volume to flow through the orifice. Variations in viscosity were observed as corresponding variations in time of flow during the test. The results of tests with the calibrated orifice are given in Table 2 and plotted in Figure 3. The data obtained using this approach show excellent correlation with a variety of fluids when compared to the known viscosity of the test fluids. While viable as a measuring technique, this method is too complex an approach for the ease of operation which was desirable for the test kit since test results would require temperature compensation using a conversion table. Additionally, a mechanical timer (of sufficient accuracy and durability) to measure the testing interval, a required component, was not readily available.

TABLE 2. CALIBRATED ORIFICE FLOW TIMES AND KINEMATIC VISCOSITY AT VARIOUS TEMPERATURES

Fuel Type AL-Code Number	MOGAS 14445-G	Stoddard Solvent 14364-F	Jet A 14366-F	Cat 1-H 14365-F
0°C				
Kinematic Viscosity, D 445, cSt	0.77	1.75*	3.20*	10.0*
Calibrated Orifice Flow Time for 30 mL Fuel, Seconds	54.1	87.5	119.2	361.8
24°C				
Kinematic Viscosity, D 445, cSt	0.63	1.25	1.76	5.15
Calibrated Orifice Flow Time for 30 mL Fuel, Seconds	52.9	78.0	98.0	257.0
40°C				
Kinematic Viscosity, D 445, cSt	0.52*	0.97	1.20	3.23
Calibrated Orifice Flow Time for 30 mL Fuel, Seconds	42.8	67.5	82.4	178.8

* Calculated from viscosity chart.

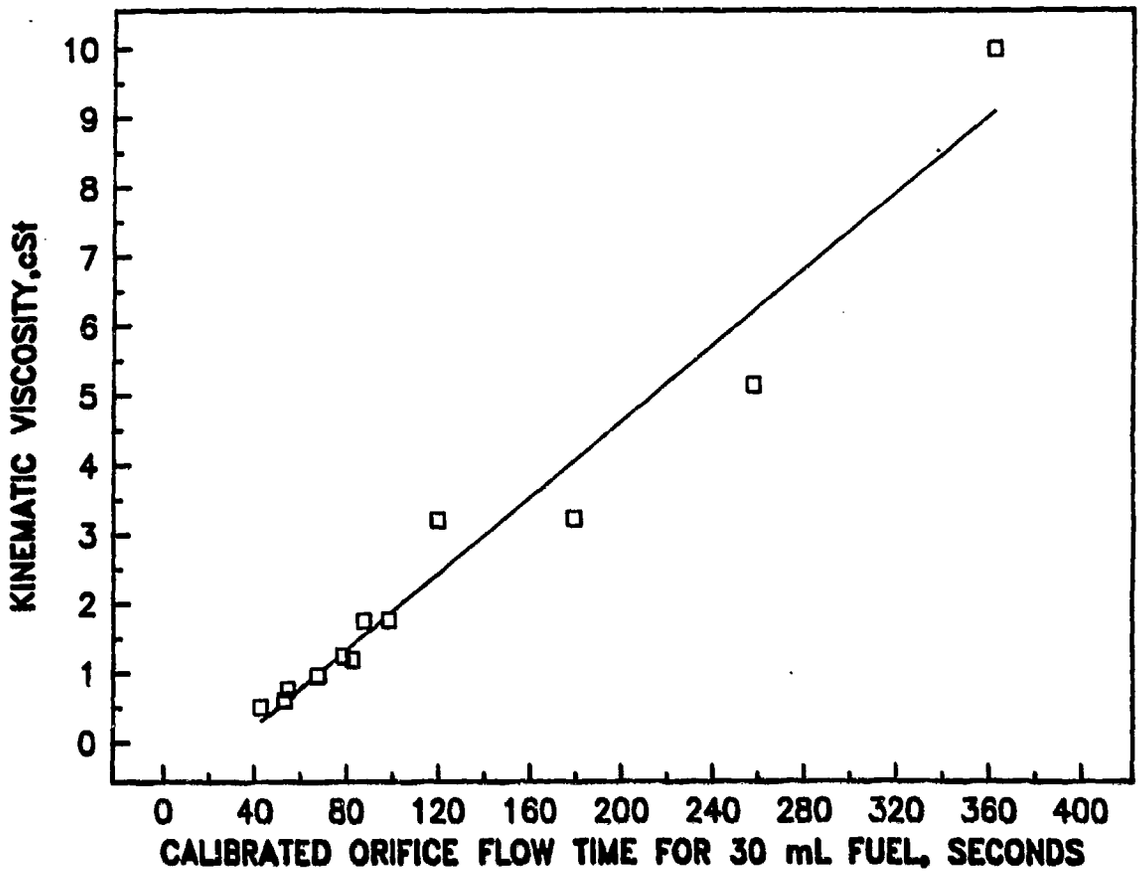

FIGURE 3. CALIBRATED ORIFICE VERSUS ACTUAL VISCOSITY

2. Falling Ball

The calibrated orifice method was abandoned in favor of the falling ball test, which was much simpler to use and was self compensating for temperature variations if reference materials were also incorporated. This method utilizes a glass tube containing a small ball. The tube is filled with the test fluid and aligned vertically, parallel to identical tubes that are filled with reference fluids representing upper and lower viscosity cutoff limits. When all tubes are simultaneously inverted, the sequence in which the balls reach the bottoms of their tubes indicates if the sample's viscosity is within the desired range.

Temperature compensation is automatically obtained with this approach by surrounding the outside surfaces of all the tubes with test fuel. This allows the tubes to reach temperature equilibrium after a relatively short residence time (approximately 1 minute). The biggest difficulty with this method was the requirement

that the reference viscosity fluids be sealed in the tubes. An approach for sealing the tubes and maintaining them without a vapor space over the temperature range of 0° to $40^{\circ}C$ was reduced to practice (Patent Disclosure No. 1716, dated 22 January 1986).

C. Visual Appearance (Clean and Bright)

1. White Beaker

The initial approach for determining the visual appearance of the fuel was to pour a volume of the fuel into a small beaker with a white bottom. The operator would then look at the bottom of the beaker through the fuel, to see if there are any contaminants in the fuel. This approach proved to be unsatisfactory for several reasons. While this method is sufficient for detecting large particles in the fuel, it is not adequately sensitive to small particles. This method is also not as sensitive to cloudiness in the fuel caused by suspended water. Additionally, if the test fuel is relatively dark in color, the appearance of contamination or water droplets in the bottom of the beaker may be obscured. If required to conduct the examination under low light conditions, there is no way that the operator could use a light source (such as a flashlight) to make the examination. Based on these shortcomings with this method, it was judged that a visual comparator would be a more acceptable approach.

2. Comparator

The visual comparator (similar to the one pictured in Figure 4) solves the problems associated with the white beaker approach. It should be noted, however, that visual appearance is not readily quantified. Although efforts have been made to provide a simple, useful visual appearance test, the visual comparator continues to be subjective in nature and more of a "clear and bright" test rather than a "clean and bright" test.

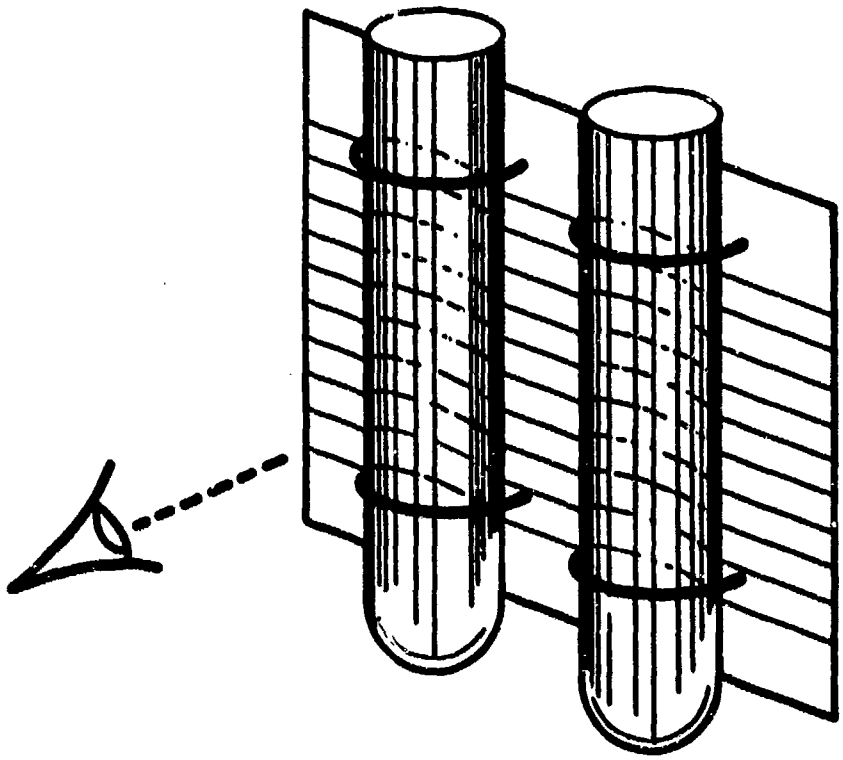

FIGURE 4. APPROACH FOR USING COMPARATOR FOR VISUAL APPEARANCE

V. EVOLUTION OF THE CURRENT CFTK

A. Density Test

The buoyant pointer approach to fluid density determination utilizes a mass which can rotate about a fixed pivot point. The mass is asymmetrically distributed around the pivot location which causes the center of buoyancy to be at a location offset to the pivot point. If the assembly is placed in a fluid, the weight distribution is altered due to the offset center of buoyancy and the assembly rotates about the pivot point to seek a new equilibrium position where the forces are balanced. Higher density fluids create more buoyant forces than lower density fluids, thus the higher the density of the fluid the greater the rotation of the assembly. The geometry of the asymmetrical weight distribution and the density of the pointer material affect the range and sensitivity of response.

The maximum rotation that can be produced by this interplay of forces is 180^{o} and the greatest sensitivity is encountered near the 90^{o} rotation point.

Since the purpose of the density test is to determine if a fuel is below a defined density limit, and 90^{o} rotation is the most sensitive zone for the instrument, it became apparent that the final design should be "fine tuned" to produce 90^{o} rotation when submerged in a fluid whose density is at the assigned lower cutoff limit (0.78 kg/L was selected as the density cutoff) for go/no-go testing of fuel density requirements.

Several designs for the density tester were empirically evaluated, modified, and refined. The first design tested was a disc of acrylic plastic with a pivot at its center. The mass distribution of the disc was then made asymmetrical by drilling holes in one half of the disc, and the counterbalance pointer was inserted into the edge of the disc near the drilled holes. This design did function in the manner expected but sensitivity proved to be insufficient. The same design was modified by reducing the thickness of the plastic disc to reduce inertial effects and the pivot design was improved to reduce friction. These modifications improved response, but sensitivity was still considered marginal. Experiments with other asymmetric geometries led to a final design which consisted of a pie-shaped wedge of plastic on one side of the pivot connected to a narrow strip of plastic on the opposite side of the pivot which contains the counterbalance pointer (see Figure 5). With this design, sensitivity and range were sufficiently improved to satisfy the design requirements when tested under laboratory conditions with various fluid and temperature combinations. (This improvement may have also been achievable by making the entire pointer mechanism buoyant in the range of densities being tested. This would have necessitated extensive testing for which no time could be allotted.)

Implementation of this approach was accomplished by using acrylic plastic for the buoyant mass with the bulk of its weight suspended on one side of the pivot point. Figure 5 is a drawing of the final design of the pointer. A counterbalance of stainless steel rod was inserted into the plastic on the opposite side of the pivot point. This steel rod serves as an indicating pointer as well as functioning as a counterbalance weight. When testing any of the experimental designs using this

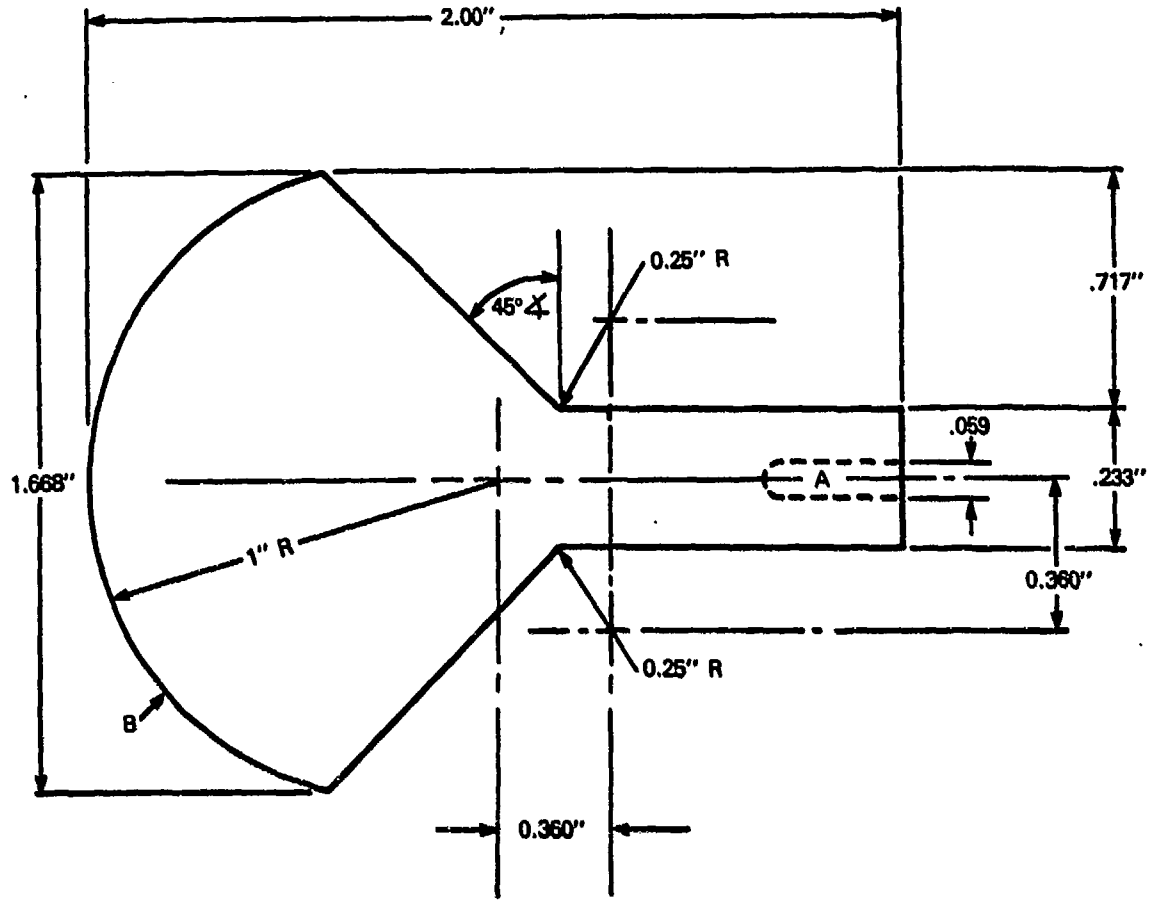

FIGURE 5. FINAL DESIGN OF CFTK DENSITY POINTER

approach, the length of the pointer was adjusted until its weight gave the proper counterbalancing effect, causing the pointer to float at 90° rotation when the assembly was submerged in fluid representing the cutoff limit for density (0.78 kg/L). This adjustment was made with the fluid at room temperature of about 24°C (75°F). In less dense fluids, the plastic sinks, causing the counterbalance pointer to rise. In denser fluids, the plastic is more buoyant, causing it to rise and the counterbalance pointer to sink.

Two major design requirements had to be achieved for this approach to be viable. The sensitivity of the responses must allow repeatable differentiation between the angular pointer position with the density reference fluid, as compared to the position achieved with less dense fluids. The second requirement is that the overall range of the pointer must be adjusted to ensure that, when the density of the cutoff limit reference fluid is altered by heating or cooling within the functional

temperature range of the tester, the angular variations of the pointer will be well within the range limits. When these requirements have been accomplished and the angular positions for the cutoff limit reference fluid established over the testing temperature range, the relative density of unknown fluids can be determined. In the tester, the density pointer will indicate a given level for the cutoff limit reference fluid. When testing an unknown fluid at that same temperature, if the pointer indicates a level higher than indicated for the reference fluid, then the questionable fluid is considered unacceptable.

As shown in Table 3, the density of a given fluid can experience a significant change over the temperature range of 0°C (32°F) to 38°C (100°F). Consequently, a simple means to temperature compensate the density tester was needed. One obvious method to accomplish this task is to generate a table containing a list of angular positions of the pointer determined for the cutoff limit reference fluid at all temperatures in the testing range. The angular position encountered with an unknown fluid at any temperature could then be compared to the position for the

TABLE 3. DENSITY CHANGES AT VARIOUS TEMPERATURES AS CALCULATED FROM ASTM D 1298, DENSITY AT 15°C

	Density, kg/L 0°C (32°F)	Density, kg/L 15°C (59°F)	Density, kg/L 23°C (74°F)	Density, kg/L 38°C (100°F)
14364-F Stoddard Solvent	0.785	0.772	0.765	0.753
14365-F Cat 1-H	0.861	0.851	0.846	0.838
14366-F Kerosene	0.807	0.796	0.790	0.780
14443-F Burner Fuel	0.881	0.871	0.866	0.857
14446-F JP-8	0.834	0.823	0.817	0.807
14447 JP-4	0.776	0.763	0.757	0.744

cutoff limit reference fluid at that temperature. This approach was rejected because it was felt to be too cumbersome. An alternate approach to temperature compensation would be for the center of gravity of the pointer to appropriately change with temperature. This could not be easily reduced to practice.

An effective and extremely simple means of temperature compensation was conceived and implemented. The angular position of the pointer was recorded with the cutoff limit reference fluid at 38°C (100°F), 24°C (75°F), and -12°C (10°F). A small thermometer was then selected, and the locations of these temperature points on the thermometer were established. The thermometer was then positioned inside the unit's case at the proper height, angular displacement, and distance from the pivot point so that the position of the pointer at the corresponding temperatures would intersect these temperature locations on the thermometer's body. Once positioned in the critical location, the thermometer proved to track the angular position of the cutoff limit reference fluid over the entire temperature range of the instrument. The pointer would always intersect with the tip of the red thermometer fluid when testing the reference fluid, regardless of temperature.

When testing an unknown fluid, the thermometer reacts to the temperature of the unknown fluid and the tip of the red fluid in the thermometer indicates where the intersection would be for cutoff limit reference fluid at this temperature. If the unknown or test fluid causes the pointer to intersect the thermometer above the red fluid level, the fluid is less dense than the reference and unacceptable (no-go). If the pointer intersects the thermometer below the tip of the red fluid, the unknown or test fluid is more dense than the reference and acceptable (go).

B. Viscosity Test

The design approach selected for viscosity determination was to fabricate reference standards, containing fluids representing selected viscosity limits. The reference fluids were sealed into glass tubes which contained a small ball. This ball would fall through the fluid when the reference tube was inverted. In operation, a sample tube which also contained a small ball, would be filled with the unknown fluid, and the cell containing the sample and reference tubes was flooded

with the unknown fluid (see Figure 6). This allowed all of the tubes to reach temperature equilibrium after a short residence time. The cell was then inverted and the sequence in which the balls fell was used to determine if the unknown fluid's relative viscosity was within the preselected viscosity range.

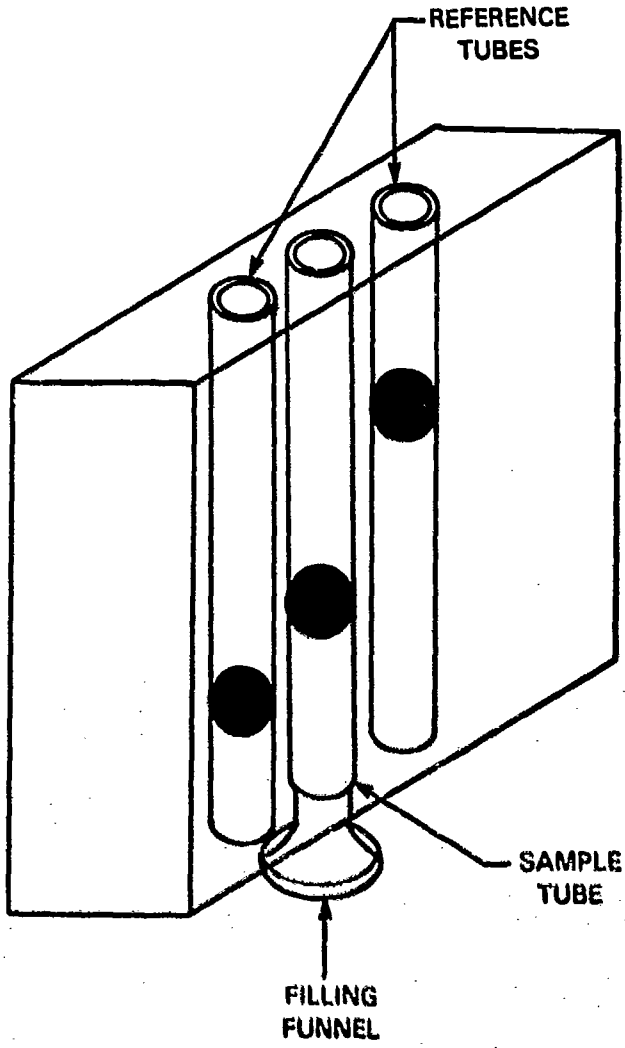

FIGURE 6. DIAGRAM OF CFTK VISCOSITY TEST
(Showing Proper "GO" Ball Fall Sequence)

When the first prototype using this approach was tested, an operational problem was encountered with the reference tubes. Air bubbles in the tubes would sometimes become trapped under the ball, affecting its fall time. To overcome this problem, a means was required to completely fill the tubes, thus eliminating

all air bubbles. The pressure within the tube must also be sufficiently high to prevent the formation of vapor bubbles, and the tube must handle fluid volume changes from thermal expansion without breaking.

The approach used to accomplish these goals was to seal one end of each reference tube by melting the glass. The opposite end was then heated and slightly flared. The reference fluids were then cooled to near their freezing points to reduce their dissolved air content and to cause maximum contraction of the fluid. A ball was then placed in the glass tube and the tube was completely filled with the cold fluid, leaving a convex meniscus at the top of the flared tube end. A thin sheet of viton elastomer was then stretched over the flared end, taking care to exclude the introduction of air bubbles (see Figure 7). A viton O-ring was rolled over the flare to seal the viton membrane in place, and heat shrink tubing was applied to the O-ring to further aid in the sealing action. As the fluid warms and expands, the elastomer stretches, allowing the tube to accommodate the increased fluid volume. The stretched elastomer creates sufficient pressure within the tube to eliminate formation of vapor bubbles.

The long-term durability of this reference tube sealing technique can only be determined by observation of its behavior over a long-term time period. If any problem is encountered, it would probably be due to diffusion through the viton membrane over a long time period. An alternate approach, which would probably extend shelf life for the reference tubes, would be to use an expandable metal bellows in place of the elastomer. This bellows could be spring loaded to overcome the effects of vapor pressure and still accommodate thermal expansion of the fluid. This conceptual approach to extending shelf life of the reference tubes could not be fully evaluated within the time and manpower constraints of this program.

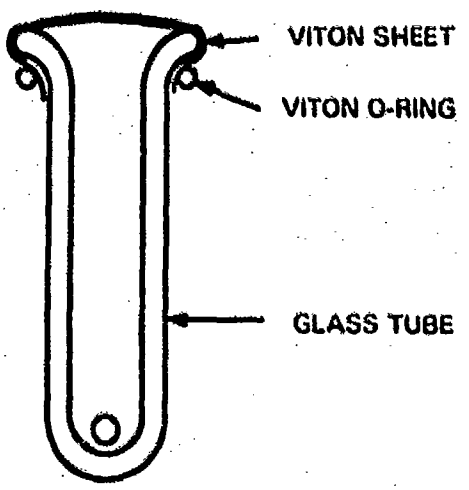

FIGURE 7. VISCOSITY REFERENCE TUBE

The elimination of air bubbles from the sample tube had to be accomplished in a different manner since neither end of the sample tube

could be permanently sealed. It was determined, however, that at least one end of the sample tube had to be temporarily sealed during testing to be certain that the ball was falling through the fluid and not simply pushing the fluid out of the tube. The first approach tested utilized a check valve on one end of the tube with the other end of the tube open. When the cell containing the tubes was filled with sample fluid, the sample tube was expected to fill, with the check valve allowing the air to escape. When the tester was inverted, the check valve would seat, thus sealing the bottom of the tube while the ball fell. In practice, this approach worked poorly due to inconsistent seating of the gravity-operated check valve.

The problem was solved in the final design by incorporating a rotating closure which would seal off both the cell's fill port and the top of the viscosity sample tube after the cell and sample tube had been completely filled with fluid. This eliminated the air bubbles in the tube and provided a positive closure to the top of the sample tube, ensuring that, when inverted, the ball would fall toward the closed end. The closure could be rotated to open position to allow draining of the sample tube and cell in preparation for the next test or storage of the test cell.

Inconsistent fall times for reference tubes containing the same reference fluids was another problem encountered during testing of this design. The problem was traced to variation in diameter of the glass tubing that had been used. This was readily solved by purchasing precision bore tubing which gave more repeatable results in the final design.

Examples of laboratory tests using this final design are provided in Tables 4 through 10. Table 4 illustrates performance when the unit was tested with the same fluid that is contained in reference tube No. 1. Sample tube No. 2 should have identical fall times when compared to tube No. 1, and the fall time difference in seconds represents the variations encountered due to slight variations between the glass tubes or the balls.

Table 5 illustrates performance when the unit was tested with the same fluid that is contained in reference tube No. 3. In this case, sample tube No. 2 should have the same fall time as compared to tube No. 3, and the fall time difference represents the variations encountered.

TABLE 4. FALLING BALL METHOD AT VARIOUS TILTS AND TEMPERATURES USING LOW VISCOSITY REFERENCE FUEL

40% Isooctane, 60% Diesel Control AL-13883, and Viscosity at 40°C, 1.32 cSt

Orientation of Test Unit	Test Temperature	Fall Time in Seconds			Fall Time Difference Tube 2 - Tube 1 in Seconds
		Tube 1	Tube 2	Tube 3	
0° Tilt	0°C (32°C)	16.6	15.5	73.8	-1.1
	23°C (73°F)	13.5	12.1	41.5	-1.4
	38°C (100°F)	12.6	11.7	27.3	-0.9
15° Left Tilt	0°C (32°F)	13.9	12.7	122.7	-1.2
	23°C (73°F)	9.8	9.3	50.3	-0.5
	38°C (100°F)	8.5	8.0	32.4	-0.5
15° Right Tilt	0°C (32°F)	13.5	12.7	128.3	-0.8
	23°C (73°F)	9.8	9.4	50.1	-0.4
	38°C (100°F)	8.4	7.6	31.8	-0.8
30° Left Tilt	0°C (32°F)	14.0	13.2	105.8	-0.8
	23°C (73°F)	11.2	10.4	55.7	-0.8
	38°C (100°F)	9.4	9.1	36.5	-0.3
30° Right Tilt	0°C (32°F)	13.2	12.4	101.4	-0.8
	23°C (73°F)	10.9	10.1	54.9	-0.8
	38°C (100°F)	9.4	9.0	36.7	-0.4

TABLE 5. FALLING BALL METHOD AT VARIOUS TILTS AND TEMPERATURES USING HIGH VISCOSITY REFERENCE FUEL

35% Mineral Oil AL-14607-L, 65% Diesel Control AL-13883-F, and Viscosity at 40°C, 5.05 cSt

Orientation of Test Unit	Test Temperature	Fall Time in Seconds			Fall Time Difference Tube 2 - Tube 1 in Seconds
		Tube 1	Tube 2	Tube 3	
0° Tilt	0°C (32°F)	16.7	76.3	77.8	+1.5
	23°C (73°F)	14.7	40.8	42.6	+1.8
	38°C (100°F)	12.0	27.6	27.3	-0.3
15° Left Tilt	0°C (32°F)	12.1	91.3	90.1	-1.2
	23°C (73°F)	9.9	49.9	50.3	+0.4
	38°C (100°F)	8.7	32.7	33.3	+0.6
15° Right Tilt	0°C (32°F)	11.6	87.4	87.5	+0.1
	23°C (73°F)	9.4	49.6	49.9	+0.3
	38°C (100°F)	8.5	34.4	33.7	-0.7
30° Left Tilt	0°C (32°F)	13.4	99.9	97.5	-2.4
	23°C (73°F)	10.7	54.9	55.6	+0.7
	38°C (100°F)	9.6	38.0	38.6	+0.6
30° Right Tilt	0°C (32°F)	13.4	100.8	100.8	0.0
	23°C (73°F)	10.7	54.3	55.4	+1.1
	38°C (100°F)		9.6	*	*

* Not Determined.

In generating the test information contained in Tables 4 and 5, the unit was operated at various temperatures and angular tilts of the device as shown in the tables. The effects of temperature and tilt angle proved to be insignificant when the tubes are compared to each other at the same temperature and tilt angle.

Tables 6 through 10 represent the results obtained with fuels or blends covering a wide range of viscosities. As shown in these tables, the fall sequence of the balls conformed to the expected results in all cases. The test fluids that were within the viscosity limits all produced a 1, 2, 3 fall sequence. Fluids outside the acceptable limit did not produce this sequence of fall.

TABLE 6. FALLING BALL METHOD AT VARIOUS TILTS AND TEMPERATURES

85% Stoddard Solvent AL-14364-F, 15% Diesel Control AL-13883-F, and Viscosity at 40°C, 1.09 cSt

Orientation of Test Unit	Test Temperature	Fall Time in Seconds			Ball-Fall Order	Correct
		Tube 1	Tube 2	Tube 3		
0° Tilt	0°C (32°F)	17.5	13.6	91.6	2-1-3	Yes
	23°C (73°F)	13.3	10.6	43.0	2-1-3	Yes
	38°C (100°F)	12.4	9.5	28.3	2-1-3	Yes
15° Left Tilt	0°C (32°F)	13.7	10.0	122.4	2-1-3	Yes
	23°C (73°F)	9.8	7.6	52.3	2-1-3	Yes
	38°C (100°F)	8.5	6.6	34.6	2-1-3	Yes
15° Right Tilt	0°C (32°F)	12.9	9.7	127.6	2-1-3	Yes
	23°C (73°F)	8.7	7.6	51.9	2-1-3	Yes
	38°C (100°F)	8.5	5.8	34.5	2-1-3	Yes
30° Left Tilt	0°C (32°F)	15.2	11.2	133.2	2-1-3	Yes
	23°C (73°F)	11.0	8.3	57.6	2-1-3	Yes
	38°C (100°F)	9.7	7.5	38.6	2-1-3	Yes
30° Right Tilt	0°C (32°F)	13.9	10.3	117.9	2-1-3	Yes
	23°C (73°F)	10.6	8.1	56.7	2-1-3	Yes
	38°C (100°F)	9.3	7.3	38.6	2-1-3	Yes

TABLE 7. FALLING BALL METHOD USING VARIOUS TEST FUELS

Orientation of Test Unit	Test Temperature	Fall Time in Seconds			Ball-Fall Order	Correct
		Tube 1	Tube 2	Tube 3		
Kerosene AL-14366-F and Viscosity at 40°C, 1.2 cSt						
0° Tilt	23°C (73°F)	14.0	12.6	42.5	2-1-3	Yes
JP-8 AL-14446-T and Viscosity at 40°C, 1.27 cSt						
0° Tilt	23°C (73°F)	14.7	13.4	44.8	2-1-3	Yes
JP-4 AL-14447-T and Viscosity at 40°C, 0.8 cSt						
0° Tilt	23°C (73°F)	15.0	7.4	42.4	2-1-3	Yes

TABLE 8. FALLING BALL METHOD AT VARIOUS TILTS AND TEMPERATURES

Stoddard Solvent AL-14364-F and Viscosity at 40°C, 0.97 cSt

Orientation of Test Unit	Test Temperature	Fall Time in Seconds			Ball-Fall Order	Correct
		Tube 1	Tube 2	Tube 3		
0° Tilt	0°C (32°F)	15.9	11.4	78.1	2-1-3	Yes
	23°C (73°F)	12.2	8.7	43.3	2-1-3	Yes
15° Left Tilt	0°C (32°F)	11.8	7.5	88.7	2-1-3	Yes
15° Right Tilt	0°C (32°F)	11.5	7.4	97.4	2-1-3	Yes
30° Left Tilt	0°C (32°F)	15.5	9.1	130.3	2-1-3	Yes
30° Right Tilt	0°C (32°F)	14.4	8.9	136.0	2-1-3	Yes

TABLE 9. FALLING BALL METHOD AT VARIOUS TILTS AND TEMPERATURES

Burner Fuel AL-14443-F and Viscosity at 40°C, 2.2 cSt

Orientation of Test Unit	Test Temperature	Fall Time in Seconds			Ball-Fall Order	Correct
		Tube 1	Tube 2	Tube 3		
0° Tilt	0°C (32°F)	15.2	20.6	60.3	1-2-3	Yes
	23°C (73°F)	12.9	16.5	42.7	1-2-3	Yes
15° Left Tilt	0°C (32°F)	10.8	24.6	70.2	1-2-3	Yes
15° Right Tilt	0°C (32°F)	12.6	33.3	118.1	1-2-3	Yes
30° Left Tilt	0°C (32°F)	16.0	41.9	142.6	1-2-3	Yes
30° Right Tilt	0°C (32°F)	15.1	41.1	156.4	1-2-3	Yes

TABLE 10. FALLING BALL METHOD AT VARIOUS TILTS AND TEMPERATURES

Cat 1-H AL-14365-F and Viscosity at 40°C, 3.2 cSt

Orientation of Test Unit	Test Temperature	Fall Time in Seconds			Ball-Fall Order	Correct
		Tube 1	Tube 2	Tube 3		
0° Tilt	0°C (32°F)	11.6	38.5	75.9	1-2-3	Yes
	23°C (73°F)	13.4	23.8	42.9	1-2-3	Yes
15° Left Tilt	0°C (32°F)	11.6	42.7	81.8	1-2-3	Yes
15° Right Tilt	0°C (32°F)	11.1	41.0	79.3	1-2-3	Yes
30° Left Tilt	0°C (32°F)	12.5	45.9	87.3	1-2-3	Yes
30° Right Tilt	0°C (32°F)	11.7	43.8	85.7	1-2-3	Yes

In the final version of the viscosity tester, the balls fall 3.5 inches. This distance was selected as a convenient distance in order to keep the overall size of the tester small. The balls are made of polytetrafluoroethylene (PTFE). PTFE was selected because it is inert and because its density is low enough to produce a reasonably short fall time during a 3.5-inch fall. When problems were encountered with contamination interfering with the fall of the sample ball, experiments were conducted to determine if a heavier ball (one that is less susceptible to contamination) would be preferable. Balls made of aluminum and bronze were tested for fall times at 3, 6, and 9-inch falls. Test fuels with viscosities of 1.3 cSt and 5.0 cSt at 40°C were used for these evaluations. These data are presented in Table 11. Note that results for bronze in each case show a relatively small difference in fall times between the 1.3 and 5.0 cSt extremes; as such, bronze was judged to be an unacceptable alternative. A 3-inch fall with the aluminum is the only option that yields results roughly equivalent to the previously selected 3-inch fall with PTFE. However, after the filter screen was installed in the filler cap, the problems with contamination subsided.

TABLE 11. FALL TIMES FOR BALLS OF VARIOUS DENSITIES AND VARIOUS FALL LENGTHS

Ball	Fall Time in Seconds					
	3-in. Fall		6-in. Fall		9-in. Fall	
	1.3 cSt	5.0 cSt	1.3 cSt	5.0 cSt	1.3 cSt	5.0 cSt
PTFE (Density = 2.3 kg/L)	10.6	37.8	22.4	68.6	39.6	10.6
Aluminum (Density = 2.7 kg/L)	9.4	29.6	19.6	59.5	29.3	94.4
Bronze (Density = 7.5 kg/L)	1.5	6.7	3.4	13.5	5.5	17.8

The final prototype viscosity tester utilizes a three-tube (one sample and two reference tubes) approach to measure viscosity. During the initial stages of development of the viscosity test, evaluations of a two-tube approach were also conducted. Under the two-tube (one sample and one reference tube) approach, the reference tube contains a fluid of a known given viscosity. The sample tube is

filled with the unknown fluid and the two tubes are inverted. The test can either be configured such that when the reference ball hits bottom, the sample ball must be in a green zone or the converse to this. The evaluations conducted gave inconsistent results across the temperature range of 0°C to 38°C. This approach may still be feasible with the proper selection of balls and reference fluid.

C. Visual Appearance

The initial concept of a visual appearance test was to use a white beaker. This was to serve as a convenient pouring vessel as well as a visual test. This approach was discarded since it is difficult to see through a dark fuel to check for water or other contamination at the bottom of the beaker.

The visual comparator was then considered as this enables one to use a visual standard for comparison. It is also possible to shine a light through a clear comparator for a better view of possible contamination.

As can be seen in Figure 8, a series of lines behind the fuel sample can be used to enable a decision to be made about the clarity of the sample. There are lines on the comparator to permit a comparison. Since all the walls of the comparator are transparent, particulate contamination can be readily seen.

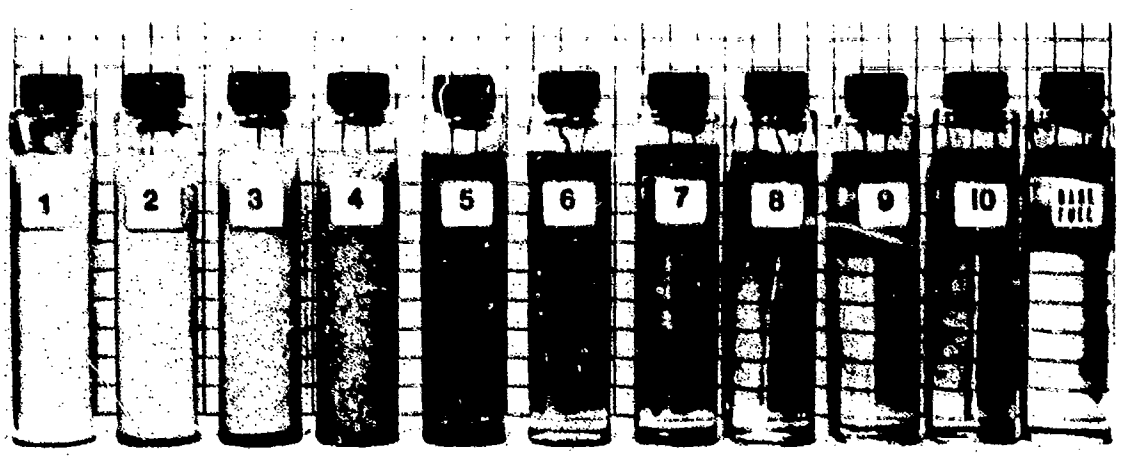

FIGURE 8. PHOTOGRAPH OF A SERIES OF DIESEL FUEL SAMPLES CONTAINING 10 VOL% DEIONIZED WATER (SAMPLES 1-7) AND THE INDICATED QUANTITY OF SURFACTANT (1-7 VOL%)
(Neat Base Fuel is Included for Comparison)

VI. CFTK CONFIGURATION

The CFTK incorporates all three of the testers in one housing. An exploded view of the final configuration is shown in Figure 9. This seemed the most efficient and simple approach for the user. Due to the sensitivity of the density and viscosity testers to small amounts of contamination, a filter screen with pores of approximately 100 micrometers was installed in the cap of the tester to prevent particles from interfering with the tests.

The initial cap design for the tester had two holes in the cap; one as a fill hole and one as a vent for the viscosity sample tube. These two holes were plugged with individual rubber stoppers. Three problems were discovered with this cap design; the stoppers were difficult to handle with gloves on, there was a tendency for air bubbles to collect in the viscosity sample tube, and filling and emptying the tester was difficult and messy. In the second prototype, the area around the two holes was machined to form a recess and a pouring spout was incorporated. Also, the two stoppers were secured into a single holder to improve ease of handling. These changes solved the problems of the air bubbles and the handling of the stoppers. There was also some improvement in the filling and emptying of the tester; however, the tester was now awkward to hold and required constant pressure on the stoppers to avoid leaks. To eliminate all of these problems, a new cap was designed. This new cap has a funnel (with an integral filter screen) for filling and emptying. This funnel also aided in the elimination of air bubbles in the sample viscosity tube. The new cap also has a positive twist closure to prevent fuel leakage. To further reduce the filling and emptying times, additional vents were installed in the cap, the top, and the bottom of the tester (see Figure 9, items 4 and 22). The vents in the top and bottom are spring-loaded valves and operate only when depressed by the user.

Since the density test requires that the tester be level during testing, a level indicator was incorporated in the tester. The level indicator consists of a pendulum/pointer and a dot and is in close proximity to the densitometer pointer for ease in viewing. When the tip of the pointer and the dot are aligned, the tester is level. No such provisions were made for the viscosity tester since experimentation showed that the viscosity test is not as sensitive to being out of level.

KEY

1. Filter Screen
2. Filling Funnel
3. Vent
4. Vent for Faster Filling
5. Top Assembly
6. Side Assembly
7. Density Test Face Plate
8. Level Indicator
9. Thermometer for Temp. Compensation
10. Rotating GO/NO-GO Range Indicator
11. Retaining Cap
12. Pin
13. PEM Nut
14. Adjustable Screw
15. Density Pointer
16. Pointer Axle
17. Chamber Dividing Wall
18. Visual Appearance Tester
19. High End Viscosity Standard
20. Viscosity Sample Tube
21. Low End Viscosity Standard
22. Vent for Faster Emptying
23. Bottom Piece
24. Viscosity Test Face Plate

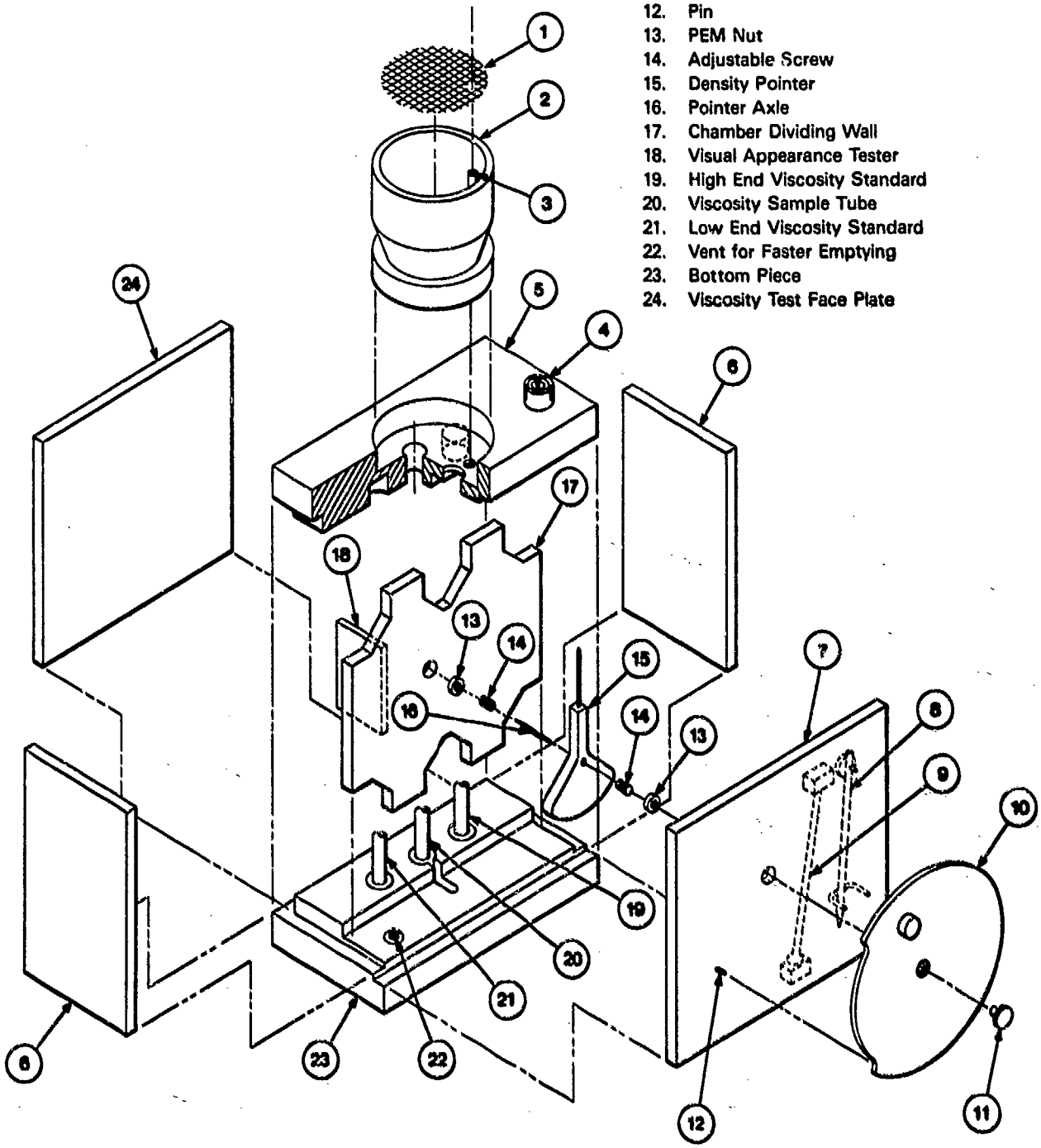

FIGURE 9. EXPLODED VIEW OF FINAL CFTK CONFIGURATION

VII. CARRYING CASE

The carrying case for the CFTK measures 15 cm x 27 cm x 17 cm. Contained in the carrying case is the combined visual appearance/density/viscosity tester, a sampling hose, and a beaker to aid in sampling and testing. The case is made of fuel-resistant, shatter-resistant plastic and has a positive (cam lock) closure. The inside of the case contains a fuel-resistant foam for shock cushioning.

VIII. QUALITY ASSURANCE TESTING

To ensure that the six prototypes were operating identically, each of the testers was tested with the same four fluids. These fluids are as follows:

Fuel	Density, kg/L, 15°C	Viscosity, cSt, 40°C
Iso-Octane	0.697	0.60
85% Stoddard Solvent/ 15% Diesel Control	0.775	1.09
Reference Diesel	0.847	2.49
35% Mineral Oil/ 65% Diesel Control	0.850	5.05

The results of this testing are given in Tables 12 through 15.

TABLE 12. RESULTS OF QUALITY ASSURANCE TESTING OF SIX CFTK PROTOTYPES WITH ISO-OCTANE

Test Unit No.	86-101	86-102	86-103	86-104	86-105	86-106
0°C						
Fill Time, seconds	12	15	15	15	21	22
Empty Time, seconds	17	23	25	24	36	29
Density, P/F	F	F	F	F	F	F
Degrees Displacement	165	170	169	169	168	168
Viscosity Fall Order	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3
25°C						
Fill Time, seconds	15	20	19	17	18	12
Empty Time, seconds	15	22	25	20	39	19
Density, P/F	F	F	F	F	F	F
Degrees Displacement	168	170	169	168	168	168
Viscosity Fall Order	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3
38°C						
Fill Time, seconds						
Empty Time, seconds	These tests were not conducted because of possible safety hazards from heating the solvent.					
Density, P/F						
Degrees Displacement						
Viscosity Fall Order						

TABLE 13. RESULTS OF QUALITY ASSURANCE TESTING OF SIX CFTK PROTOTYPES WITH 85/15

Test Unit No.	86-101	86-102	86-103	86-104	86-105	86-106
0°C						
Fill Time, seconds	16	14	22	13	31	18
Empty Time, seconds	18	22	18	18	37	20
Density, P/F	P	P	Cutoff	P	Cutoff	Cutoff
Degrees Displacement	55	45	56	48	50	58
Viscosity Fall Order	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3
25°C						
Fill Time, seconds	18	13	15	15	14	14
Empty Time, seconds	18	13	17	18	50	17
Density, P/F	Cutoff	Cutoff	Cutoff	P	Cutoff	Cutoff
Degrees Displacement	92	95	96	98	95	98
Viscosity Fall Order	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3
38°C						
Fill Time, seconds	15	14	15	13	36	21
Empty Time, seconds	18	32	17	17	30	22
Density, P/F	*	*	Cutoff	*	Cutoff	Cutoff
Degrees Displacement	110	110	112	112	115	100
Viscosity Fall Order	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3	2-1-3

* Just in red zone.

TABLE 14. RESULTS OF QUALITY ASSURANCE TESTING OF SIX CFTK PROTOTYPES WITH DIESEL CONTROL

Test Unit No.	86-101	86-102	86-103	86-104	86-105	86-106
0°C						
Fill Time, seconds	38	23	25	50	45	56
Empty Time, seconds	16	22	22	22	25	18
Density, P/F	P	P	P	P	P	P
Degrees Displacement	15	12	11	10	10	10
Viscosity Fall Order	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3
25°C						
Fill Time, seconds	16	20	23	15	17	18
Empty Time, seconds	16	22	22	19	15	18
Density, P/F	P	P	P	P	P	P
Degrees Displacement	15	12	13	15	15	15
Viscosity Fall Order	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3
38°C						
Fill Time, seconds	16	15	18	20	20	19
Empty Time, seconds	18	17	17	17	18	19
Density, P/F	P	P	P	P	P	P
Degrees Displacement	15	15	15	15	15	15
Viscosity Fall Order	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3

TABLE 15. RESULTS OF QUALITY ASSURANCE TESTING OF SIX CFTK PROTOTYPES WITH 35/65

Test Unit No.	86-101	86-102	86-103	86-104	86-105	86-106
0°C						
Fill Time, seconds	180	120	150	120	180	180
Empty Time, seconds	20	30	37	35	25	25
Density, P/F	P	P	P	P	P	P
Degrees Displacement	10	10	10	10	10	10
Viscosity Fall Order	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3
25°C						
Fill Time, seconds	20	30	33	35	36	36
Empty Time, seconds	20	22	21	22	24	23
Density, P/F	P	P	P	P	P	P
Degrees Displacement	10	15	15	15	15	15
Viscosity Fall Order	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3
38°C						
Fill Time, seconds	15	22	25	26	59	56
Empty Time, seconds	20	20	20	19	47	19
Density, P/F	P	P	P	P	P	P
Degrees Displacement	10	12	10	11	10	10
Viscosity Fall Order	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3	1-2-3

IX. CONCLUSIONS AND RECOMMENDATIONS

A tester has been developed which will allow an unskilled operator to predict with reasonable probability if an undocumented fuel is potentially usable in Army compression-ignition engines and turbine-powered ground equipment. The reliability/confidence level of the tester to predict usability in a compression-ignition engine is yet to be determined in a separate program.

Density and viscosity cutoff limits were selected based on justifiable criteria. However, further testing and verification, especially in conjunction with engine tests, are required to establish the best limits.

The visual appearance test in the tester is not quantitative. There is not a simple, quantitative visual appearance test known at this time. This remains the most subjective part of the tester.

As noted earlier, density and viscosity are not reliable predictors of the overall performance of a fuel in a compression-ignition engine. Because of this, there will probably be acceptable fuels that the tester will reject. Likewise, there is the possibility that some unacceptable fuels will not be rejected. The frequency of each of these occurrences will depend on where the cutoff limits are set. Obviously, it is more desirable to reject some acceptable fuels than to accept some unacceptable fuels. Additionally, the acceptability limits will vary with climate (environmental engine start and operate temperature) and with the sensitivity of particular engines. The ability of a surrogate engine to start and run on a fuel designated as acceptable by the CFTK could be established as final acceptance criteria.

After acceptance of the prototype tester, it will be necessary to develop approaches to simplify its manufacture as the current prototype is far too complex to manufacture at a reasonable cost.

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SLCRO-CB (DR GHIRARDELLI) 1
P O BOX 12211
RSCH TRIANGLE PARK NC 27709-2211

PROG MGR, TACTICAL VEHICLE
ATTN: AMCPM-TV 1
WARREN MI 48397

CDR
TRADOC COMBINED ARMS TEST ACTIVITY
ATTN: ATCT-CA 1
FORT HOOD TX 76544

CDR
105TH S & T BATTALION
5TH INFANTRY DIV (MECH) 1
FORT POLK LA 71459

CDR
TOBYHANNA ARMY DEPOT
ATTN: SDSTO-TP-S 1
TOBYHANNA PA 18466

CDR
US ARMY DEPOT SYSTEMS CMD
ATTN: AMSDS-RM-EFO 1
CHAMBERSBURG PA 17201

CDR
US ARMY LEA
ATTN: DALO-LEP 1
DALO-LEI 1
NEW CUMBERLAND ARMY DEPOT
NEW CUMBERLAND PA 17070

HQ, EUROPEAN COMMAND
ATTN: J4/7-LJPO (LTC LETTERIE) 1
VAIHINGEN, GE
APO NY 09128

CDR
US ARMY GENERAL MATERIAL & PETROLEUM ACTIVITY
ATTN: STRGP-FW (MR PRICE) 1
BLDG 247, DEFENSE DEPOT TRACY
TRACY CA 95376

PROJ MGR, LIGHT ARMORED VEHICLES
ATTN: AMCPM-LA-E 1
WARREN MI 48397

CDR
US ARMY FOREIGN SCIENCE & TECH CENTER
ATTN: AMXST-MT-I 1
AMXST-BA 1
FEDERAL BLDG
CHARLOTTESVILLE VA 22901

CDR
AMC MATERIEL READINESS SUPPORT ACTIVITY (MRSA)
ATTN: AMXMD-MO (MR BROWN) 1
LEXINGTON KY 40511-5101

PROJECT MANAGER, LIGHT COMBAT VEHICLES
ATTN: AMCPM-LCV-TC 1
WARREN, MI 48397

HQ, US ARMY T&E COMMAND
ATTN: AMSTE-TO-O 1
AMSTE-CM-R-O 1
AMSTE-TE-T (MR RITONDO) 1
ABERDEEN PROVING GROUND MD 21005-5006

CDR, US ARMY TROOP SUPPORT COMMAND
ATTN: AMSTR-ME 1
AMSTR-S 1
AMSTRE-E 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

TRADOC LIAISON OFFICE
ATTN: ATFE-LO-AV 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

HQ
US ARMY TRAINING & DOCTRINE CMD
ATTN: ATCD-SL-5 (MAJ JONES) 1
FORT MONROE VA 23651-5000

CDR
US ARMY NATICK RES & DEV LAB
ATTN: STRNA-YE (MR KAPLAN) 1
STRNA-U 1
NATICK MA 01760-5000

CDR
US ARMY TRANSPORTATION SCHOOL
ATTN: ATSP-CD-MS (MR HARNET) 1
FORT EUSTIS VA 23604-5000

PROJ MGR, PATRIOT PROJ OFFICE
ATTN: AMCPM-MD-T-C 1
U.S. ARMY MISSILE COMMAND
REDSTONE ARSENAL AL 35898

CDR
US ARMY QUARTERMASTER SCHOOL
ATTN: ATSM-CD 1
ATSM-TD 1
ATSM-PFS 1
ASTM-DTN 1
FORT LEE VA 23801

HQ, US ARMY ARMOR CENTER AND FORT KNOX
ATTN: ATSB-CD 1
FORT KNOX KY 40121

CDR
101ST AIRBORNE DIV (AASLT)
ATTN: AFZB-KE-J 1
AFSB-KE-DMMC 1
FORT CAMPBELL KY 42223

CDR
US ARMY WESTERN COMMAND
ATTN: APLG-TR 1
FORT SCHAFTER HI 96858

CDR
COMBINED ARMS COMBAT DEVELOPMENT ACTIVITY
ATTN: ATZL-CAT-E 1
ATZL-CAT-A 1
ATZL-TIE (MR DODSON) 1
FORT LEAVENWORTH KA 66027-5300

CDR
US ARMY LOGISTICS CTR
ATTN: ATCL-MS (MR A MARSHALL) 1
ATCL-C 1
FORT LEE VA 23801-6000

PROJECT MANAGER
PETROLEUM & WATER LOGISTICS
ATTN: AMCPM-PWS 1
4300 GOODFELLOW BLVD
ST LOUIS MO 63120-1798

CDR
US ARMY FIELD ARTILLERY SCHOOL
ATTN: ATSF-CD 1
FORT SILL OK 73503-5600

CDR
US ARMY ENGINEER SCHOOL
ATTN: ATZA-TSM-G 1
ATZA-CDM 1
ATZA-CDD 1
FORT BELVOIR VA 22060-5606

CDR
US ARMY INFANTRY SCHOOL
ATTN: ATSH-CD-MS-M 1
FORT BENNING GA 31905-5400

CDR
MILITARY TRAFFIC MANAGEMENT
COMMAND
ATTN: MT-SA (MR DOWD) 1
WASHINGTON DC 20315

DIR
US ARMY MATERIALS & MECHANICS
RESEARCH CENTER
ATTN: SLCMT-M 1
SLCMT-O 1
WATERTOWN MA 02172-2796

PROG MGR, TANK SYSTEMS
ATTN: AMCPM-M1E1-SM 1
AMCPM-M60 1
WARREN MI 48397

CDR
US ARMY ARMOR & ENGINEER BOARD
ATTN: ATZK-AE-AR 1
ATZK-AE-LT 1
FORT KNOX KY 40121

CDR
6TH MATERIEL MANAGEMENT CENTER
19TH SUPPORT BRIGADE 1
APO SAN FRANCISCO 96212-0172

CHIEF, U.S. ARMY LOGISTICS
ASSISTANCE OFFICE, FORSCOM
ATTN: AMXLA-FO (MR PITTMAN) 1
FT MCPHERSON GA 30330

CDR
US ARMY SAFETY CENTER
ATTN: PESC-SSD (MR BUCHAN) 1
FORT RUCKER AL 36362

U.S. ARMY DEVELOPMENT AND
EMPLOYMENT AGENCY
ATTN: MODE-FDD-CSSB
(MAJ GROSSMAN) 1
FORT LEWIS WA 98433-5000

CDR
U.S. ARMY LABORATORY COMMAND
ATTN: AMSLC-TP (DR GONANO) 1
ADELPHI MD 20783-1145

DEPARTMENT OF THE NAVY

COMMANDING GENERAL
US MARINE CORPS DEVELOPMENT
& EDUCATION COMMAND
ATTN: DO74 (LTC WOODHEAD) 1
QUANTICO VA 22134